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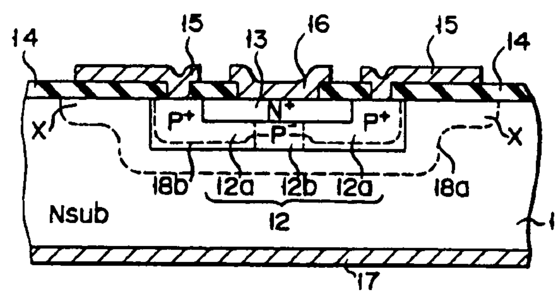
(54) Semiconductor device with a field plate electrode structure.

(57) In a pnp transistor with a field plate electrode structure, a p-type base region (12) is constituted by a high impurity concentration region (12a) and a low impurity concentration region (12b) and forms a p-n junction with an emitter region (13) formed therein, so that breakdown is caused by punch-through occurring in the p-type base region (12) contacting a base electrode (15) serving as a field plate electrode.

F I G. 2



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Semiconductor device

The present invention relates to an improvement of a semiconductor device, such as a diode, a transistor, thyristor, and the like, which can have a high breakdown voltage by adopting a field plate electrode structure.

Fig. 1 shows a high-breakdown voltage npn bipolar transistor having a conventional field plate electrode structure. Referring to Fig. 1, p^+-type base region 2 is formed in a major surface of n-type silicon substrate 1, and n^+-type emitter region 3 is formed in base region 2. Oxide film 4 is formed on the major surface of substrate 1, and portions of oxide film 4 on base and emitter regions 2 and 3 are etched to form a contact hole. Base electrode 5 contacts base region 2 and emitter electrode 6 contacts emitter region 3 through the contact hole. Base electrode 5 contacts base region 2, and extends on oxide film 4 by a predetermined distance toward outside of the semiconductor device beyond the upper end of the p-n junction between substrate 1 and base region 2, thus forming a field plate electrode structure. In addition, collector electrode 7 is formed on the back surface of substrate 1.

In the bipolar transistor with the above field plate electrode structure, when a negative voltage is applied to base electrode (field plate electrode) 5 or emitter electrode 6 and a positive voltage is applied to collector electrode 7, depletion layer 8 which is formed at a p-n junction between collector region 1 and base region 2 (indicated by a broken curve in Fig. 1) extends below the extending portion of base electrode (field plate electrode) 5. For this reason, electric field concentration does not easily occur when compared with a case wherein a base electrode is not extended. Therefore, when the semiconductor device with the field plate electrode structure has a small diffusion depth, for example, even if the diffusion depth of base region 2 is about 5µm, if substrate 1 has a specific resistance of several tens of Ω• cm, a high breakdown voltage of 500 V or higher can be obtained.

Such an improvement of breakdown voltage can be applied not only to a transistor but also to other semiconductor devices such as a diode, a thyristor, and the like.

As described above, in the semiconductor device with the field plate electrode structure, since depletion layer 8 extends below the field plate electrode, a high breakdown voltage can be obtained. However, an electric field strength becomes maximum immediately below the end of the field plate electrode (indicated by X in Fig. 1), and breakdown occurs in this portion. If a large current flows during breakdown, substrate 1 causes crystal destruction (breakover destruction) and cannot often be reused.

The present invention has been made to eliminate the above drawback, and has as its object to provide a semiconductor device which adopts a field plate electrode structure to obtain a high breakdown voltage with a relatively small diffusion depth and will not cause breakover destruction.

According to the present invention, there is provided a semiconductor device with a field plate electrode structure having a first diffusion layer of a second conductivity type formed in a major surface of a semiconductor substrate of a first conductivity type and forming a p-n junction between the first diffusion layer and the substrate; a second diffusion layer of the first conductivity type formed in the first diffusion layer of the second conductivity type and forming a p-n junction between the second diffusion layer and the first diffusion layer of the second conductivity type; an insulating film formed on the major surface of the substrate; and an electrode contacting at least the first diffusion layer of the second conductivity type through an opening formed in the insulating film, and extending outward on the insulating film by a predetermined length beyond an upper end of a p-n junction between the substrate and the first diffusion layer of the second conductivity type, wherein breakdown, when it occurs, is initiated by punch-through occurring in the first diffusion layer.

As a means for starting breakdown due to punchthrough in the diffusion layer of the second conductivity type, the diffusion layer of the second conductivity type comprises a high impurity concentration region and a low impurity concentration region, so that the diffusion layer of the first conductivity type forms a p-n junction with the low impurity concentration region constituting the diffusion layer of the second conductivity type. With this structure, since the depletion layer can easily extend from a low-concentration diffusion layer constituting the diffusion layer of the second conductivity type toward the diffusion layer of the first conductivity type, punch-through easily occurs between the low-concentration diffusion layer and the diffusion layer of the first conductivity type. The impurity concentration of the low-concentration diffusion layer is appropriately selected so that punch-through occurs at a voltage lower than a voltage causing breakdown immediately below the end of the field plate.

Alternatively, the diffusion layer of the second conductivity type is constituted by regions respectively having a relatively large diffusion depth and a relatively small diffusion depth, so that the diffusion layer of the first conductivity type forms a p-n junction with the small diffusion depth region constituting the diffusion layer of the second conductivity type. With this structure, since a depletion layer extending from the small diffusion depth region constituting the diffusion layer of the second conductivity type to the diffusion layer of the first conductivity type has a small distance, punch-through easily occurs between the small diffusion depth region and the diffusion layer of the first conductivity type. The diffusion depth is appropriately selected so that punch-through occurs at a voltage lower than a voltage causing breakdown immediately below the end of a field plate.

Still alternatively the diffusion layer of the second conductivity type is constituted by regions of large and small diffusion depths. The large diffusion depth region has a high impurity concentration, and the small diffusion depth region has a low impurity concentration. The diffusion layer of the first conductivity type forms a p-n junction with the region having the small diffusion depth and low impurity concentration and constituting the diffusion layer of the second conductivity type. With this structure, a depletion layer can be easily extended from the region having the small diffusion depth and low impurity concentration toward the diffusion layer of the first conductivity type. Since the distance to the diffusion layer of the first conductivity type is small, punch-through easily occurs between the region having the small diffusion depth and low impurity concentration and the diffusion layer of the first conductivity type. The diffusion depth and/or the impurity concentration of the region having the small diffusion depth and low impurity concentration is appropriately selected so that punch-through occurs at a voltage lower than a voltage causing breakdown immediately below the end of a field plate.

According to the above semiconductor devices, since breakdown is caused by punch-through between the diffusion layers of the first and second conductivity types, breakdown immediately below an electrode (field plate) can be prevented, and a substrate can be protected from crystal destruction.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a sectional view of a high breakdown voltage bipolar transistor of a conventional field plate electrode structure;

Fig. 2 is a sectional view of a high breakdown voltage bipolar transistor of a field plate electrode structure according to first example 1 of the present invention;

Figs. 3 and 4 are sectional views of high breakdown voltage bipolar transistors of a field plate electrode structure according to second and third examples 2 and 3 of the present invention;

Fig. 5 is a sectional view of a high breakdown voltage diode of a field plate electrode structure according to fourth example 4 of the present invention; and

Figs. 6 to 8 are sectional views of high breakdown voltage diodes of a field plate electrode structure according to fifth to seventh examples 5 to 7 of the present invention.

The present invention will be described by way of its examples.

Example 1

Fig. 2 is a sectional view of an npn bipolar transistor with a field plate electrode structure. Referring to Fig. 2, base region 12 serving as a first diffusion region is formed in a major surface of n-type silicon substrate 11. The diffusion depth of base region 12 is about 5μm, and region 12 is constituted by p^+-type diffusion layer 12a having a surface concentration of about 1×10^{18} cm^{-3}, and p^--type diffusion layer 12b having a surface concentration of about 5×10^{16} cm^{-3}. N^+-type emitter region 13 is formed in base region 12 to form a p-n junction with p^--type diffusion layer 12b. Oxide film 14 is formed on the major surface of substrate 11. Portions of oxide film 14 on diffusion layer 12a constituting base region 12 and on emitter region 13 are etched to form a contact hole. Base electrode 15 contacts base region 12 and emitter electrode 16 contacts emitter region 13 through the contact hole. Base electrode 15 contacts base region 12, and extends outward on oxide film 14 by a predetermined distance beyond the upper end of the p-n junction between substrate 11 and base region 12, thus forming a field plate electrode structure. In addition, collector electrode 17 is formed on the back surface of substrate 11.

In the bipolar transistor shown in Fig. 2, when a negative voltage is applied to base electrode 15 or emitter electrode 16 and a positive voltage is applied to collector electrode 17, a depletion layer is formed in a p-n junction between substrate 11 and base region 12. More specifically, depletion layer 18a extends toward substrate 11 and depletion layer 18b extends toward base region 12. Depletion layer 18b at the side of base region 12 does not significantly extend in diffusion layer 12a constituting base region 12 but considerably extends in

diffusion layer 12b. Therefore, depletion layer 18b in diffusion layer 12b easily reaches emitter region 13. As a result, punch-through occurs between layer 12b and region 13. The impurity concentration of diffusion layer 12b constituting base region 12 is selected so that a voltage causing punch-through is lower than a voltage causing breakdown in a portion immediately below base electrode (field plate electrode) 15 (indicated by X in Fig. 2). Thus, breakdown is caused by punch-through between base region 12 and emitter region 13, i.e., in the first diffusion region. Therefore, crystal destruction of substrate 11 immediately below base electrode (field plate electrode) 15 can be prevented.

Example 2

Fig. 3 shows a second example of the present invention. In this example, diffusion layers 12a and 12b constituting base region 12 have different diffusion depths. Layer 12a is formed to be deep, and layer 12b is formed to be shallow. Note that in this example, layers 12a and 12b are high-concentration p^+-type diffusion layers. Other structural details are essentially the same as those in the example shown in Fig. 2. The same reference numerals in Fig. 3 denote the same portions as in Fig. 2, and a detailed description thereof will be omitted.

In the bipolar transistor shown in Fig. 3, when a negative voltage is applied to base electrode 15 or emitter electrode 16 and a positive voltage is applied to collector electrode 17, a depletion layer is formed in a p-n junction between substrate 11 and base region 12. More specifically, depletion layer 18a extends toward substrate 11 and depletion layer 18b extends toward base region 12. Since diffusion layer 12b is formed to be shallow, the depletion layer in layer 12b easily reaches emitter region 13. As a result, punch-through occurs between layer 12b and emitter region 13. The diffusion depth of diffusion layer 12b is selected so that a voltage causing punch-through is lower than a voltage causing breakdown in a portion immediately below the end of base electrode (field plate electrode) 15 (indicated by X in Fig. 3). Breakdown is initiated due to punch-through between layer 12b and emitter region 13, i.e., in the first diffusion region. Therefore, crystal destruction of substrate 11 immediately below the end of base electrode - (field plate electrode) 15 can be prevented.

Example 3

Fig. 4 shows a third example of the present invention. In this example, base region 12 is constituted by p^+-type diffusion layer 12a having a surface concentration of about 1×10^{19} cm^{-3} and p^--type diffusion layer 12b having a surface concentration of about 5×10^{15} cm^{-3}. Layers 12a and 12b have different diffusion depths so that layer 12a is formed to be deep, e.g., about 5µm, and layer 12b is formed to be shallow.

Other structural details are essentially the same as those in the examples shown in Figs. 2 and 3. The same reference numerals in Fig. 4 denote the same portions in Figs. 2 and 3, and a detailed description thereof will be omitted.

In the bipolar transistor shown in Fig. 4, when a negative voltage is applied to base electrode 15 or emitter electrode 16 and a positive voltage is applied to collector electrode 17, a depletion layer is formed in a p-n junction between substrate 11 and base region 12. More specifically, depletion layer 18a extends toward substrate 11 and depletion layer 18b extends toward base region 12. Since diffusion layer 12b comprises a low impurity concentration region, the depletion layer extends considerably in layer 12b. In addition, since layer 12b is formed to be shallow, the depletion layer in layer 12b can easily reach region 13. As a result, punch-through occurs between layer 12b and emitter region 13. The diffusion depth and/or the impurity concentration of diffusion layer 12b constituting base region 12 is selected so that a voltage causing punch-through is lower than a voltage causing breakdown in a portion immediately below the end of base electrode (field plate electrode) 15 - (indicated by X in Fig. 4). Thus, breakdown is caused by punch-through between layer 12b and emitter region 13, i.e., in the first diffusion region. Therefore, crystal destruction of substrate 11 immediately below the end of base electrode (field plate electrode) 15 can be prevented.

Example 4

Fig. 5 is a sectional view of a diode with a field plate electrode structure to which the present invention is applied. Referring to Fig. 5, p-type diffusion layer 22 serving as a first diffusion region is formed in the major surface of n-type silicon substrate 21. N-type diffusion layer 23 for causing punch-through is formed in diffusion layer 22. Oxide film 24 is formed on the major surface of substrate 21, and portions thereof on diffusion layers 23 and 22 are etched to form a contact hole. Electrode (field plate electrode) 25 contacting diffusion layers 22 and 23 through the contact hole is

formed. Electrode 25 extends outward by a predetermined distance on oxide film 24 beyond the upper end of the p-n junction between substrate 21 and diffusion layer 22, thus forming a field plate electrode structure. In addition, rear electrode 26 is formed on the back surface of substrate 21.

Example 5

Fig. 6 shows a modification of Fig. 5. P-type diffusion layer 22 is constituted by high concentration p^+-type diffusion layer 22a and low concentration p^--type diffusion layer 22b, so that layer 22b forms a p-n junction with layer 23. Other structural details are the same as those in the diode shown in Fig. 5.

Example 6

Fig. 7 shows another modification of Fig. 5. Diffusion layers 22a and 22b constituting diffusion layer 22 have different diffusion depths so that layer 22a is diffused relatively deep and layer 22b is diffused relatively shallow. Other structural details are the same as those in the diode shown in Fig. 5.

Example 7

Fig. 8 shows a modification of Figs. 6 and 7. p^+-type and p^--type diffusion layers 22a and 22b constituting p-type diffusion layer 22 are diffused relatively deep and relatively shallow, respectively. Other structural details are the same as those in the diodes shown in Figs. 6 and 7.

In the diodes shown in Figs. 5 and 8, when a negative voltage is applied to electrode 25 and a positive voltage is applied to back-surface electrode 26, a depletion layer is formed in a p-n junction between substrate 21 and p-type diffusion layer 22. Depletion layer 27a extends toward substrate 21 and depletion layer 27b extends toward layer 22. When depletion layer 27b at the side of diffusion layer 22 further extends, it reaches diffusion layer 23, and punch-through occurs, thereby causing breakdown.

Since a voltage causing punch-through is set to be lower than a voltage causing breakdown in portion immediately below the end of electrode - (field plate electrode) 25, breakover destruction can be prevented, and substrate 21 immediately below the end of electrode (field plate electrode) 25 can be protected from crystal destruction.

In the structure shown in Fig. 6, since diffusion layer 22 is constituted by p^+-type diffusion layer 22a and p^--type diffusion layer 22b, depletion layer 27b does not significantly extend in layer 22a but considerably extends in layer 22b. Punch-through easily occurs between layers 22b and 23. In this manner, a voltage causing punch-through can be controlled by changing the impurity concentration of diffusion layer 22.

In the structure shown in Fig. 8, a voltage causing punch-through can be controlled not only by the impurity concentrations of diffusion layers 22a and 22b constituting diffusion layer 22 but also by the diffusion depths of these diffusion layers.

Note that a voltage causing punch-through can be controlled by only changing the diffusion depth without changing the impurity concentration of diffusion layer 22.

According to the present invention as described above, a long-life semiconductor device which adopts a field plate electrode structure to obtain a high breakdown voltage with a relatively small diffusion depth and will not cause breakover destruction can be provided.

Claims

1. A semiconductor device with a field plate electrode structure characterized by comprising:

a first diffusion layer (12, 22) of a second conductivity type formed in a major surface of a semiconductor substrate (11, 21) of a first conductivity type and forming a p-n junction between the first diffusion layer and said substrate;

a second diffusion layer (13, 23) of the first conductivity type formed in said first diffusion layer of the second conductivity type and forming a p-n junction between the second diffusion layer and said first diffusion layer of the second conductivity type;

an insulating film (14, 24) formed on the major surface of said substrate; and

an electrode (15, 25) contacting at least said first diffusion layer of the second conductivity type through an opening formed in said insulating film, and extending outward on said insulating film by a predetermined length beyond an upper end of a p-n junction between said substrate and said first diffusion layer of the second conductivity type,

and characterized in that breakdown, when it occurs, is initiated by punch-through occurring in said first diffusion layer.

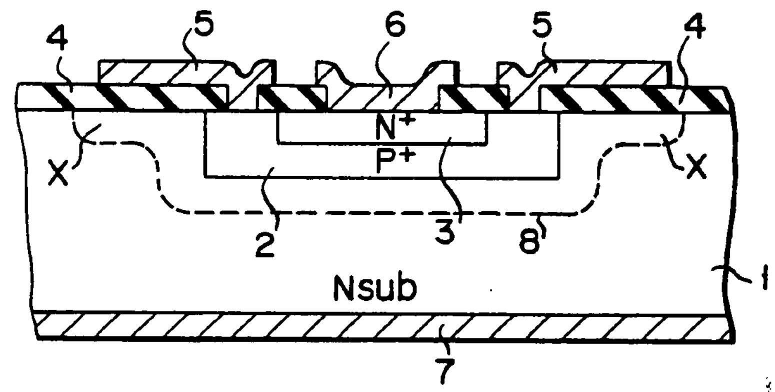
2. A semiconductor device according to claim 1, characterized in that said electrode (15, 25) contacts said first diffusion layer of the second conductivity type.

3. A semiconductor device according to claim 1, characterized in that said electrode (15, 25) commonly contacts the first diffusion layer of the second conductivity type and said second diffusion layer of the first conductivity type.

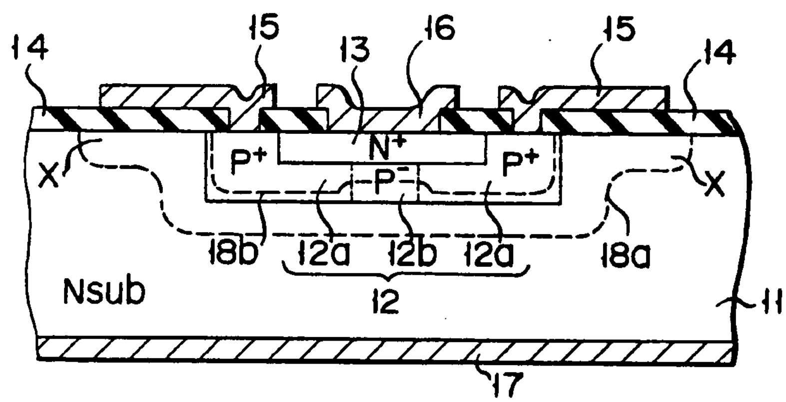
4. A semiconductor device according to any one of claims 1, 2 or 3, characterized in that said first diffusion layer (12, 22) of the second conductivity type is constituted by a high impurity concentration region (12a, 22a) and a low impurity concentration region (12b, 22b).

5. A semiconductor device according to any one of claims 1, 2, 3 or 4, characterized in that said first diffusion layer (12, 22) of the second conductivity type is constituted by a deep region (12a, 22a) and a shallow region (12b, 22b).

6. A semiconductor device according to claim 4, characterized in that said high impurity concentration region (12a, 22a) comprises a deep region (12a, 22a), and said low impurity concentration region (12b, 22b) comprises a shallow region (12b, 22b).



F I G. 1



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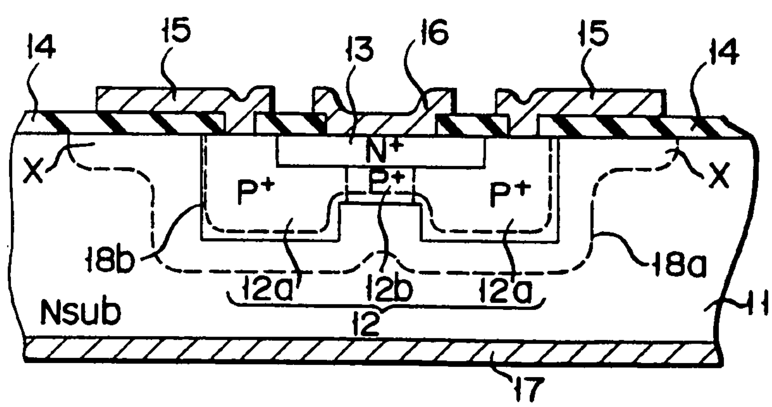
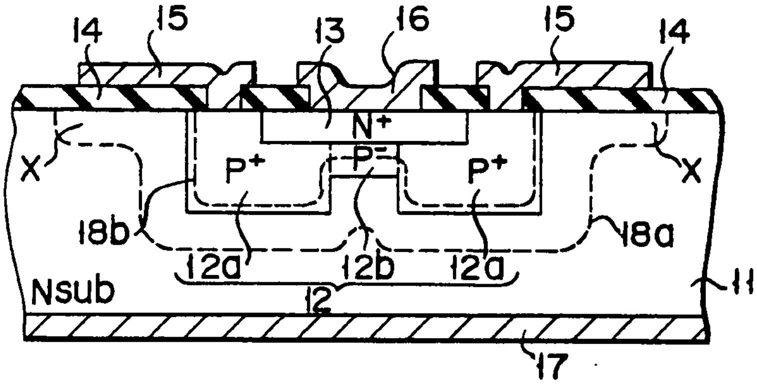


F I G. 3

F I G. 4



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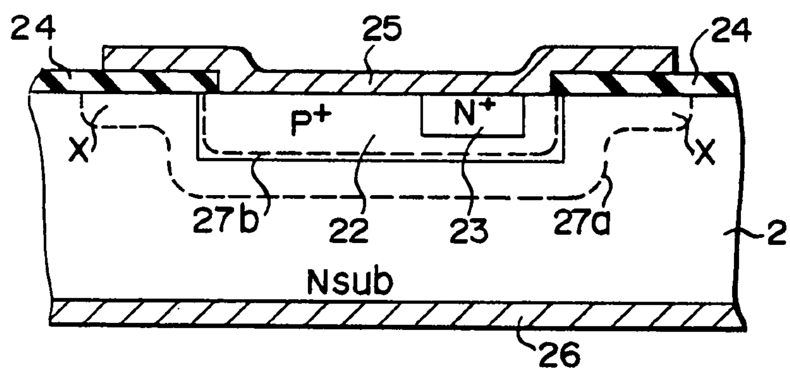

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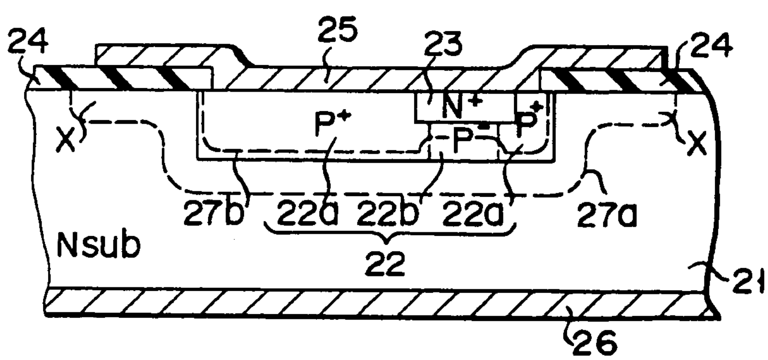
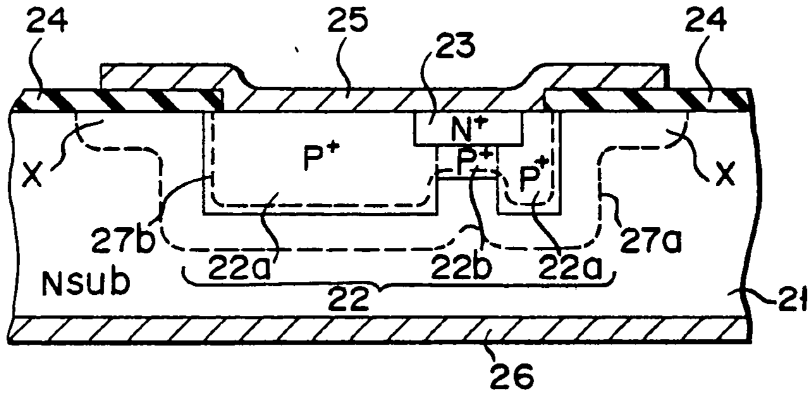


F I G. 7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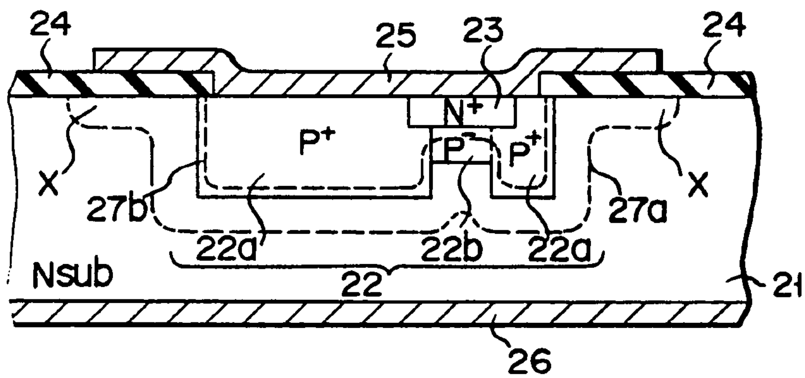
F I G. 8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